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ORIGINAL RESEARCH

Enhancement of Agricultural Productivity through Application of Compost Produced Using Rice Husks (*Oryza sativa*) and Water fern (*Azolla pinnata*)

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Abstract

Purpose: Composting agro-wastes enhances plant growth with minimal health and environmental threats. Thus, this study focused on the potential of composting rice husk *(Oryza sativa)* with water fern plants*(azolla)* to increase agricultural productivity with minimal health and environmental pollutions.

Method: The study employed laboratory experimentation and analysis. In experimental design the Minitab software was used to design these experiments whereby two factors were considered which are the particle size (2 mm, 3 mm and 4 mm) and mixing ratio (1:3; 1:1; 3:1 and 4:0; 0:4). Fifteen (15) wood compartments with dimensions of 30 cm x 30 cm x 35 cm each cube of maximum carrying capacity of 5 kg were developed.

Results: The results for physical and chemical properties of feedstock's showed that rice husks contained 8.55% of Moisture Content, pH (6.15), total organic carbon (46.1%), ash content (20.6%), PO_4^{3-} (2475 mg/kg), K (5042 mg/kg), Na (1490.4 mg/kg), total nitrogen (0.735%) and Carbon to Nitrogen ratio (34.21). *Azolla* contained Moisture Content (93.48%), pH (6.73), TOC (42.67%), TN (3.255%), C/N ratio (13.02%), PO_4^{3-}, (4262.5mg/kg), K (1268 mg/kg), and Na (7379.52 mg/kg). The composting made using samples with particle size of < 2 mm were observed to support the growth of *Amaranthus spinous* quickly with the average growth rate of 0.9572 cm/day than other compost produced with particles size of 3 mm and 4 mm

Conclusion: This study shows that there is a potential of composting rice husks with *azolla* for nutrient resource recovery to support crop productivity.

Keywords: Biofertilizer, Composting, Feed stocks, Nutrients, Resource recovery, Waste management

Introduction

In Tanzania it is estimated that over 80% of the population engages in agricultural production, and half (1/2) of the national income and three quarters (3/4) of goods export in the country is contributed by agricultural sector (Leonard and Riwa, 2023). Though the sector employs a large population of Tanzania, its contribution to national GDP has been decreasing from 29.0 percent in 2015 to 26.6 percent in 2019 The decrease is attributed by structural transformation of economic activities, shifting of rural population to urban areas and challenges facing the practice and production in the agricultural sector. The agricultural sector in Tanzania is faced by several challenges including low productivity of land/low fertility, labour and production inputs, over dependence on rain-fed agriculture, inadequate investment in agricultural training, research and extension services, inadequate capital for accessing agricultural technologies and others (Mng'ong'o *et al*., 2021). Inadequate investment in agricultural training, research and technology development have resulted in low productivity and capacity in agro-processing, poor quality of crop produced, post-harvest loss, environmental degradation due to poor cultivation systems and inappropriate application of agro-chemicals and fertilizers (Suvi *et al*., 2021). The Agricultural Sector Development Programme Phase II (ASDP II) (2017) indicated that Tanzania applies low amount of fertilizer about 8-10 kg of fertilizer/per hectare in the farmlands compared to other countries like Malawi which applies 27 kg per hectare. The low application of fertilizer is contributed by several factors including inadequate capacity to purchase inorganic fertilizer, low technology for production of organic fertilizer, limited knowledge to understand the required amount of fertilizer and other. This calls for different stakeholders to take part in addressing agricultural challenges including research and development in production of organic fertilizer since Tanzania is blessed with adequate resources for production of organic fertilizer such as rice husks.

Rice is regularly consumed and is considered as an important crop for food security for over half of the world's population (Seleiman *et al*., 2022; Isimikalu *et al*., 2023) and is expected that by 2030, rice production at a global scale will increase to 567 million tonnes (Mohidem *et al*., 2022). It is grown on every continent except Antarctica and the extent of paddy cultivation covers about 1% of the earth's surface and is ranked as the second to wheat in terms of cultivation area and production (Seleiman *et al*., 2022; Leonard and Riwa, 2023;). Production of rice is dominated by Asia where rice is the only food crop that can be grown during the rainy season in the waterlogged rice paddies (Bandumula, 2018). The consumption of rice in African continent is also expected to increase driven by population growth, dietary changes and crop production on the existing arable land (Mohidem *et al*., 2022; Balasubramanian *et al*., 2007).

In Tanzania, 18% of the households are engaged in rice production (Joseph, 2013) which is the second most grown food and commercial crop after maize, in the country (Leonard and Riwa, 2023). It is further estimated that 99% of the rice in the country is produced by smallholder farmers with farm sizes ranging between 0.5 to 3 hectares (Joseph, 2013; Wilson and Lewis, 2015). Rice husks are a key byproduct associated with rice production which is not considered to be of economic value to millers (Isimikalu *et al*., 2023; Njogu *et al*., 2015; Khan et al., 2012). The worldwide annual rice husk output is about134 million tons (Quispe et al., 2017), out of which 97% of the husks is produced in the developing countries (Abubakar, 2016). In Tanzania, it is common to find piles of rice husks around rice milling machines, left uncollected, indicating that majority of the population have no alternative of utilizing such resources which ultimately causes environmental pollution. According to Bakari *et al.*, (2023) rice husks produced in Tanzania is more than 3.2 million metric tons per year. Rice husks (RHs) are produced in large quantities over millions of tons worldwide and only small quantities of rice husks are recovered through composting, briquette production (Wilson and Lewis, 2015), biogas production (Okeh *at al.*, 2014), and animal feeds (Aondoaver, 2014). In most cases, farmers and business men are interested with rice grains, leaving behind rice husks at the milling machines which at the end of the day undergoes open burning which is not environmentally friendly. This calls a need of establishing affordable and beneficial technologies of utilizing such agro wastes.

Various studies suggest that composting agro industrial waste have potential of recovering resources which can be used for agricultural production (Seleiman *et al.*, 2022; Thiyageshari *et al.*, 2018 and Khan et al., 2012). Materials with lignin and cellulose can be degraded economically through inoculating with lignocellulolytic microorganism (Thiyageshari *et al.*, 2018) and produce compost suitable for plant growth. A study done by Kumar *et al.,* (2009) and Gao *et al.*, (2018) indicated that rice husks contains 35 - 40% cellulose, 15 - 20% hemicellulose and 20 - 25% lignin and *azolla* contains 28.23 - 29.51% cellulose, 10.82 - 11.4% hemicellulose and 7.82 - 8.32% lignin (Gupta *et al.*, 2018). Typical compositions of rice husks and *azolla* indicate their potential for resource recovery (Gupta *et al.,* 2018; Gao *et al.*, 2018). Nevertheless, despite of the potential of composting these materials for resource recovery, they are haphazardly left on the environment causing environmental and health risks (Seleiman *et al.*, 2022).

Today, the world is witnessing the demand of food due to population growth and land degradation (Isimikalu *et al.*, 2023; Andoaver, 2014). The most common practice has been to use synthetic fertilizers to improve the degraded soil (Seleiman *et al.*, 2022) which ultimately causes health and environmental pollution. A study done by Seleiman *et al.* (2022) revealed that *azolla* plant can be composted and enhance plant growth. Thus, there is a need of establishing proper way of handling and recovering these resources which are not easily decomposed due to the presence of lignin as complex chemical structure providing strength and makes rice husks highly resistant to microbial degradation (Thiyageshari *et al.*, 2018).

Therefore, this study intended to assess the potential of active composting technology for production of compost using rice husk mixed with *azolla* for the purpose of recovering organic manure and recycling important nutrients for agricultural production while solving environmental, health and social-economic problems triggered by poor management of rice husks. The compost made from agro waste are considered to be environmentally friendly, raw materials are readily available and the technology can be adopted by small and large-scale farmers and hence increase crop productivity towards meeting sustainable development goal 1 and 2 (No poverty and Hunger to all) by 2030. In addition, composting of rice husks provides an alternative way of managing this biomass (Isimikalu *et al.*, 2023) which is currently unutilized in Tanzania and sometimes regarded as waste burnt and add up to greenhouse gases which also result into substantial loss of nutrients such as nitrogen and sulphur (Isimikalu *et al.*, 2023).

Materials and methods

Feedstocks and its preparation

The feedstock's used in this study were rice husks (*Oryza sativa*) collected from milling machines located in Tandale ward, Kinondoni district while *azolla* (*azolla pinnata*) were collected at Mtongani area located in Temeke municipal in Dar es Salaam region. These areas were selected for feedstock collection due to their abundances in the study area. All feedstock after collection into sacks of 20 kg plastic bags from respective collection sites were transported to Ardhi University for preparations and experimentation. Rice husks were weighted by using Salter universal hanging scale with capacity of 200 kg. The rice husk (*Oryza sativa*) was sieved to different particle size of 2 mm, 3 mm and 4 mm since small particle size (<4 mm) provides a large surface area for microbial decomposition, and then collected into the sacks for temporary storage before the mixing process took place.

Preparation of feedstock composting ratios

The five-mixing ratio of different weights for *azolla* and rice husks were established and named as sample R_1, R_2, R_3 , R_4, and R_5 where the last two ratios were used as control as shown in Table 1. The two controls namely R_4 and R_5 included only rice husks (*Oryza sativa*) and *azolla* (water fern plants) respectively. The composting processes were conducted naturally by regulating only moisture content to be between 40% - 60%.

Table 1. Composting ratio between *azolla*, water fern plant (A) and Rice husk, Oryza sativa (B)

Sample	Ratio (A : B) kg	(A : B) g
R1	3 : 1	3000 : 1000
R2	1 : 1	2000 : 2000
R3	1 : 3	500 : 1500
R4	0 : 4	0 : 4000
R5	4 : 0	4000 : 0

Methodology

Fifteen (15) wood compartments were developed and used with dimensions of 30 x 30 x 35 cm (height, width and length) for single compartment, respectively, and maximum carrying capacity of 5 kg per each cube as shown in Fig. 1.

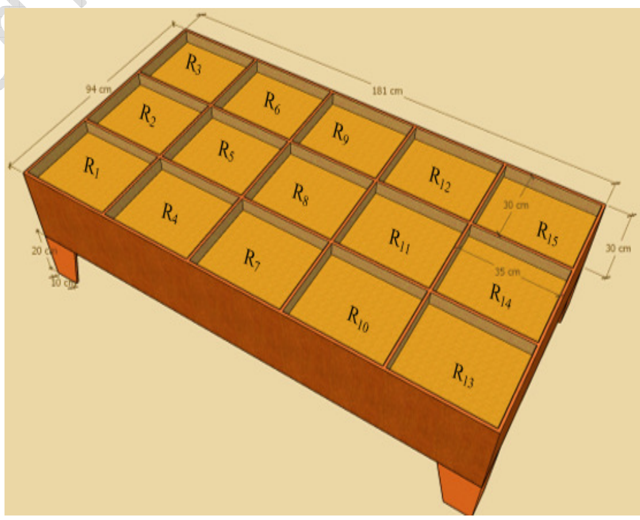

Figure1. A 3D view structure of wood bin composting system with its dimensions

Mixing process

In feedstock preparation, mixing ratio comprised of three runs where by two runs comprised five ratios and one had three mixing ratios. The first run included the particle size of 2 mm of rice husk with a mixing ratio namely R5, R8, R9, R12 and R13. The second run was particle size of 3 mm of rice husks with a mixing ratio namely R1, R2 and R7, the third run was particle size of 4 mm with a mixing ratio of R3, R4, R6, R10 and R11 and the remained two mixed ratios were for controls.

Laboratory analysis

The quality of compost produced from rice husk mixed with *azolla* was established by analyzing their physiochemical and biological properties which included temperature, moisture content, pH, electric conductivity, potassium (K), total nitrogen (TN), phosphates (PO_4^{3-}), total organic carbon (TOC), heavy metals (Cu, Pb, Zn and Cd) and C:N ratio.

Moisture content (MC)

Moisture content was calculated using equation 1 (AOAC, 2000);

$$MC(\%) = \frac{(W2-W1)-(W3-W1)}{(W2-W1)} x100 \quad (1)$$

Where by W_1 weight of the crucible in gram, W_2 is weight of the crucible with wet sample in gram (g) and W3 is weight of the crucible with sample after drying at 105°C.

Organic matter content (OM)

Organic matter content was determined by loss on ignition method described by AOAC (2000) as given in equation 2.

$$\%OM = \frac{((W3-W1)-(W4-W1))}{(W3-W1)} x\,100 \quad (2)$$

Where; -W_1 represents the weight of empty crucible in gram, W_2 is weight of the crucible with wet sample in gram, W_3 is weight of the crucible with sample after drying at 105°C and W_4 represents weight of the ash with crucible after drying up to 562°C in an oven.

Total nitrogen

Total nitrogen was determined by using a Kjedahl Nitrogen test as described by AOAC, (2000). The percentage of Total Nitrogen was calculated using equation 3.

$$\%TN = \frac{[(a-b)\times N \times 1.4\, x\, MC\ ]}{WS} \quad (3)$$

Whereby; N- normality of standard H_2SO_4 used, a - volume (ml) of H_2SO_4 required to titrate the sample to color change, b - volume in (ml) of 0.05N H_2SO_4 required to titrate of blank to color change, Ws- sample dry weight in grams, MC - Moisture Content and 1.4 (weight of nitrogen in gram) = 14 x 10^{-3} x 100% (14 is the atomic mass of N.

Potassium (K) and Heavy metals

Potassium and heavy metals were determined in the feedstock materials by using Atomic Absorption Spectrophotometer. The concentrations were converted mathematically from mg/L to mg/kg using equation 4.

$$\text{Conc}\left({}^{mg}/_{kg}\right) = \text{Conc}\left({}^{mg}/_{l}\right) \times \frac{(V \text{ in } L)}{W S} \qquad (4)$$

whereby; volume (V) in L= 0.002 L of aqua regia + 0.01 L of distilled water

Weight of sample (WS) = 0.51 g = 0.00051 kg

$$\text{Conc}\left({}^{mg}/_{kg}\right) = mg/l \times \frac{(0.002L + 0.01)}{0.00051kg} \quad = 24L/Kg$$

Determination of performance of compost produced in plant growth

The performance was determined based on the plant growth rate. During the germination and growth of *Amaranthus spinosus*, the heights of stem and leaves were established using a mathematical ruler, widths of leaves and the number of leaves in *Amaranthus spinosus* to evaluate the average daily growth rate. The measurement was recorded from 1st day, 4th ,8th, 12th to 18th. The experimental setup had four plots which included selected three compost based on C/N ratio of compost in each particle size namely, 2 mm (Plot 1 - P1), 3 mm (Plot 2 - P2) and 4 mm (Plot 3 - P3) and control (Plot 4 - P4) which had no compost. Plot 1 included compost from R12, Plot 2 from R1 and three from R10 while plot 4 did not include compost. Selected of compost based on C/N ratio was based on the similar C/N ratio in all particle sizes which meet the recommended standard of C/N ratio ranging from 20:1 to 30:1. This range promotes healthy plant growth and preventing nutrient imbalances or deficiencies. Mathematically the growth rate was calculated by taking the average change in height of the stem to its time taken to grow.

$$Growth\ rate = \frac{\Delta Height\ of\ steam\ (cm)}{\Delta Time\ (day)}$$

Statistical analysis

Analysis of variance (ANOVA) and Pearson correlation was carried out where P values ($p<0.05$) were considered to present significant differences. Also, descriptive analysis was conducted using Excel Microsoft version 10.1 to establish means and standard deviations of analytical results.

Results and discussion

The physical and chemical properties of feedstock's material are presented in Table 2. The initial composition of the raw material used for composting helped to monitor the parameters essential for microbial decomposition during the composting process and helped to forecast the quality of the compost produced. The findings revealed that Water fern plant had high moisture content of 93.48% compared to 8.55% of rice husks while EC was 4.16 mS/cm in water fern plant compared to 1.76 mS/cm in rice husks. The moisture content results are somehow in alignment or slightly less than that presented by Bhaskaran and Kannnanan (2015), and Brand *et al*., (2017), respectively as indicated in Table 2. Ash content was 20.6% in rice husks compared to 9.86% in the water fern plant. The obtained ash contents for rice husk was almost the same as what obtained by Bronzeoak, (2000) but for *azolla* was different from what obtained by Hossain *et al.,* (2021) Bhaskaran and Kannnanan, (2015). Phosphate concentration was 4262.5 mg/kg compared to 2475 mg/kg while potassium concentration was 5042 mg/kg in rice husks compared to 1268 mg/kg in fern plant. The C/N ratio was 34.21 in rice husks compared to 13.02 in fern plant indicating that materials chosen for composting had Carbon and Nitrogen content of different magnitude. These results were different from the findings from other studies as indicated in Table 2. The difference might be attributed to the environmental conditions where the plants were grown which affect the distribution of chemicals.

Table 2. Initial composition of feedstock materials before compost production as characterized in in terms of physical and chemical composition**.**

Physical composition of feedstocks material			
Parameters	**Water fern plant (*azolla*)**	**Rice husks (*Oryza sativa*)**	**Results from other studies**
Moisture contents (%)	93.48	8.55	AZP: 92.25 (Bhaskaran and Kannnanan, 2015), RHs: 8 - 12 (Brand *et al*., 2017)
pH	6.73	6.15	AZP: 6.9-8.5±1.3 (Chandra *et al.,* 2012)
E.C (mS/cm)	4.16	1.76	AZP: 8.4±0.2 (Chandra *et al.,* 2012)
Total organic carbon (%)	42.67	46.10	RHs: 28.23 (Misra *et al*., 2003)
Organic matter (%)	73.02	79.40	AZP: 82.65 ±0.01 (Pillai *et al.,* 2002)
Ash content (%)	9.86	20.60	RHs: 20-29 (Bronzeoak, 2000), AZP: 2 (Bhaskaran and Kannnanan, 2015)
Phosphate (mg/Kg)	4262.5	2475	AZP: 50- 120 mg/kg (Kleinman *et al*., 2004).
Potassium (K) (mg/Kg)	1268	5042	AZP: 0-2-4.5% (Singh *et al.,* 1977)
Total nitrogen TN (%)	3.255	0.735	RHs: 0.31 (Thiyageshwari *et al.,* 2018) AZP: 3.22±0.55 (Costa *et al.,* 1999).
C/N ratio	13.02	34.21	25:1-30:1 (Mohammad *at el.,* 2004)

Heavy metal contamination in raw feedstock materials

The results of heavy metal concentrations in feedstock are presented in Table 3. During composting process, the concentration of heavy metals in feedstock remains the same except for the water-soluble metals, thus increasing their concentration in compost. Depending on the plant species, the soil type and the quality of the compost applied to the soil, accumulation of heavy metals in plant may lead to plant toxicity and decrease plant growth (Dubey *et al.,* 2018). The presence of heavy metal in soil results into the production of free radicals and reactive oxygen species in plant cells which alters metabolism, growth and biomass yield (Goyal *et al*., 2020). Hence, it is important to establish the concentration of heavy metals in feedstock used in composting to make sure that the compost is free from heavy metal contamination.

Except cadmium concentration in water fern plant which was in the range of 12.41 ± 0.1 mg/kg greater than 0.7 mg/kg recommended values by European heavy metal standards, the rest of analyzed metals, i.e. copper, lead, zinc and chromium were within the recommended standards as shown in Table 3, giving the assurance that the quality of compost is expected to have no heavy metals for user's safety.

Table 3. Heavy metal concentration in feedstock material before composting

Parameters	Measured values (mg/kg) in water fern plants	Rice husks (*Oryza Sativa*) feedstock	Recommended values (mg/kg) by European (EU) heavy metals standard	Remarks
Copper (Cu)	6.05 ± 0.01	8.93 ± 0.128	70	Accepted
Lead (Pb)	9.70 ± 0.001	9.07 ± 0.072	45	Accepted
Zinc (Zn)	80.06 ± 0.02	53.62 ± 0.1	200	Accepted
Cadmium (Cd)	12.41 ± 0.1	0.29 ± 0.01	0.7	Not accepted
Chromium (Cr)	< DL (< 0.01)	< DL (< 0.01)	70	Accepted

Temperature

For the 40th days of composting process, the mesophilic phase of temperature ranged from 25 -40℃, the lowest temperature was observed in the first days of composting process for all 15th composted ratios as described in Fig. 2a, b and c. In the thermophilic phase of temperature, over 40℃ was observed in most of the composted ratios except in samples R_5, R_8, R_9, R_{12} and R_{13} as described in Fig. 2a which attained a peak temperature of 49°C in 10th, 11th , 12th and 13th day of composting process. The peak thermophilic temperature of 45°C was observed in 10th day for ratios R_1, R_2, R_{14}, and R_{15} in Fig. 2 (b) and 44°C in R_1, R_4, R_6, and R_{10} as described in Fig. 2(c). Cooling phase of temperature 25 - 40℃ was observed on the average from the 16th day of all composted ratios during the composting process to 40th day, as described in all Figures. The acclimation stage of microorganisms was responsible for the lowest temperature at the beginning, as a portion of energy was utilized to maintain microbial activity while the rest contributed to the increasing temperature within the pile during the composting process (Xie *et al.*, 2017). The microbial decomposition process is affected by temperature and also results in increased temperature which is given out as heat and also lowers moisture content which was utilized by microorganisms in their metabolic activities.

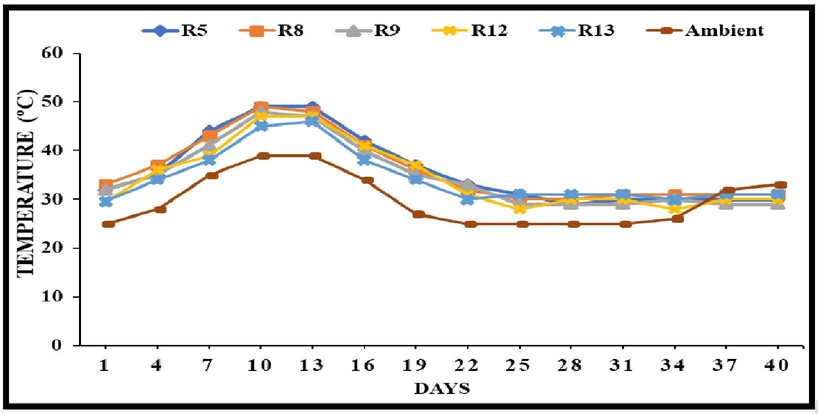

Figure 2a. In-situ temperature variation during bin-composting process by considering rice husks with the particle size of <2 mm

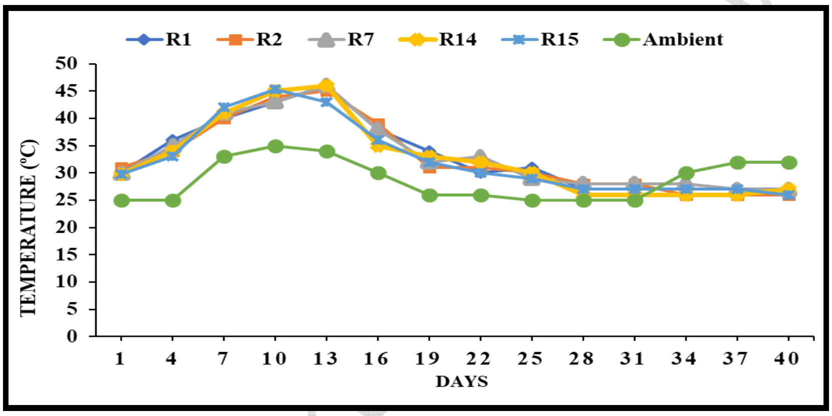

Figure 2b. In-situ temperature variation during bin-composting process by considering rice husks with the particle size of <3 mm

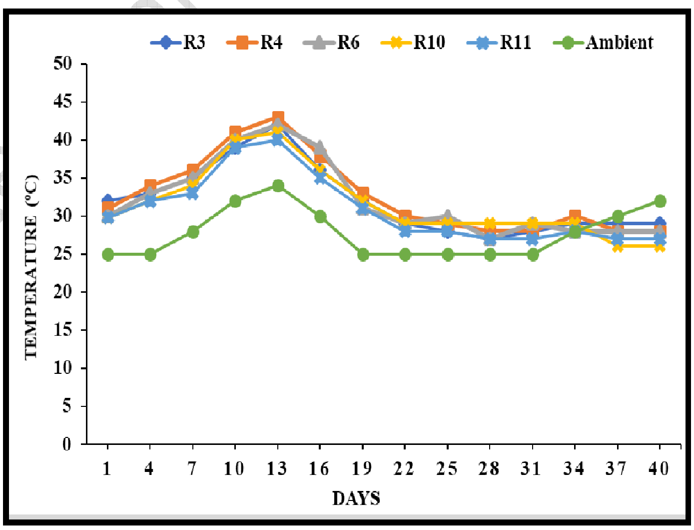

Figure 2c. In-situ temperature variation during bin-composting process by considering rice husks with the particle size of <4 mm

Smaller particles provide large surface area for microorganism to attach enable fast decomposition rate and release more heat to the compost pile evenly and to withstand excessive drying at the surfaces. Yang *et al*., (2019) describes the particle size with > 3 cm can result into excess aeration which will contribute to dropping the temperature and lastly slowing down the composting process. High temperature is essential for destruction of pathogenic organisms at 55˚C and undesirable weed seeds at critical point of elimination is 62˚C (Nengwu, 2007).

A drop in temperature in the compost pile before material stabilization can mean that the pile is becoming anaerobic and should be aerated (Zein *et al*., 2015). The temperature pile depends on pile size, the ambient (surrounding) temperature, the moisture content and the degree of aeration (Sarkar *et al*., 2015). Although small particle size increase surface area available for microbes to attack, so reducing the particle size of feedstock material can catalyze the composting process as observed in composted ratios R5, R8, R9, R11 and R13 which were reached early to mature compost.

Also, reduction in the size of materials reduces the volume of the compost pile hence saving space in bin compost system as described by Shishvan and Asghari (2018). The inability of the process to reach the peak temperature of 55°C among the composted ratios might have been influenced by differences in the quality of feedstock among ratios composted, frequency of turning, the addition of water for maintaining optimal moisture content ranging between 40 - 60% and other environmental condition as described by (Misra *et al*., 2003).

Moisture content

Moisture content dropped in composting ratios with the particle size of 2 mm during day 5 and day 10 when the temperature was 49°C whereby in R9 it dropped from (59.2% to 56.2%), R8 (57% to 50.8%), R12 (60.3% to 56%) and R13 (60.4% to 60%). At the temperature of 45˚C, R15 dropped from (66% to 65%) which had rice husks with particle size of 3 mm. Also, at temperature of 44 ˚C the moisture content dropped in sample R3 which contained rice husks of particle size of 4 mm from 57.8% to 51.2%, R4 (60.1% to 51.7%) and R11 (59.3% to 46.2%). The correlation analysis indicated that the variation in the moisture content between 40 to 60% has an effect on the interior of the pile. From the analysis, a coefficient value r > 0.7 was obtained indicating that there was a significant positive correlation between the MC and the Temperature in the interior of the pile. The heat stored within the pile is dependent on the moisture content of the composting feedstock's material.

Sample R15 which is a control was observed to have higher moisture content above recommended range with moisture content of 66% and 64% in 5th and 10th day as shown in Fig. 3b respectively. The habitant where feedstocks were collected might contribute to much higher moisture content because *azolla* (water fern plant) is an aquatic species growing in fresh water in tropical, sub-tropical and warm-temperature region as described by Kollah et al. (2016). The lowest moisture content was 44.35% observed in sample R_{11} at 20th and 30th days as presented in Fig. 3c. Generally, the moisture content was within recommended standard of 40 - 60%. Matured compost generally has moisture contents between 35 - 45% as reported by Leslie *et al*., (2022).

During the 40th day the highest pH of 8.4 was observed in samples R8 and R12 as illustrated in Fig. 4a and the lowest pH of 5.36 was observed in R5. Monitoring of pH is important since it may affect the rate of decomposition and decrease the growth of microorganisms. Vázquez *et al*., (2015) described that the optimum pH for microbial activities should range between 5.5 to 8 and mature composts usually have pH-values ranging from 7 to 8 (Ma'ruf *et al.,* 2017). This indicates that during the composting process, the pH values ranged within the recommended optimal level to all twelve composted ratios as illustrated in Figs. 4a, 4b and 4c except in R_5, R_8, and R_{13} on 5th which were 5.36, 5.45, and 5.40 respectively as described in Fig. 4a and this is possibly due to decomposition of soluble compounds such as sugars which produce organic acids and hence decrease pH value (Hemidat, 2018).

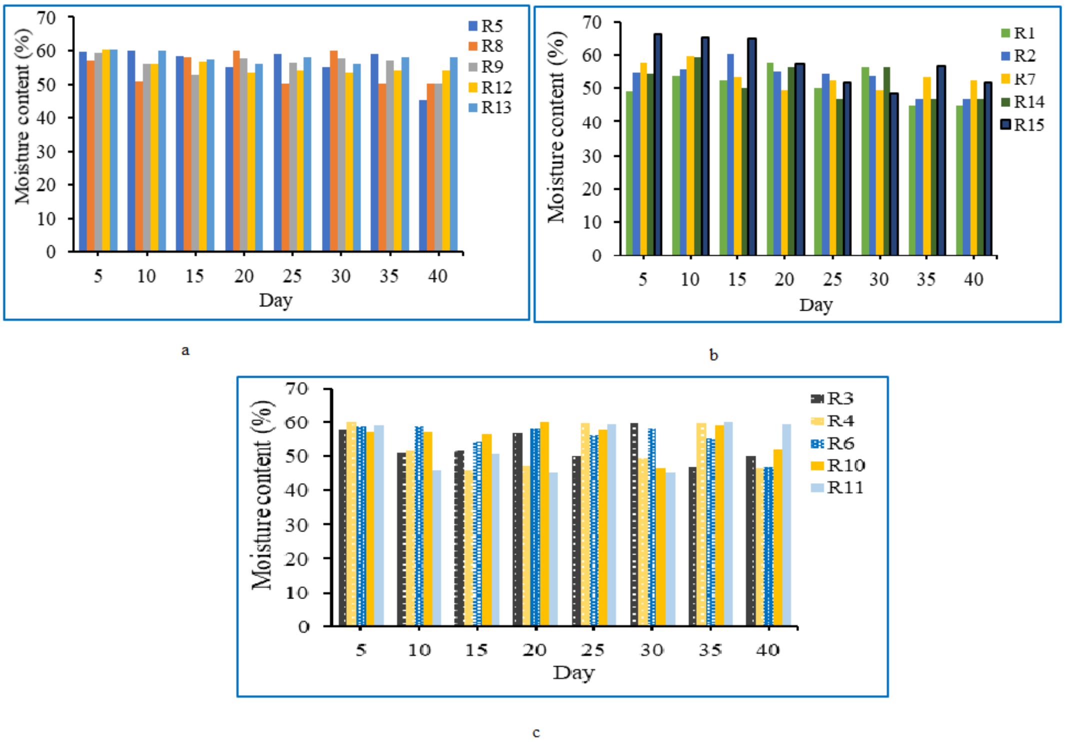

Figure 3. Moisture content variation during in-composting process by considering rice husks with the particle size of < 2 mm, <3 mm and <4 mm as described a, b, c respectively.

Microbial results

From the 1st day to the 14th day, a population of microbes was observed to increase as the temperature increased in composted ratios. The rice husks composted with the particle size of < 2 mm at the peak temperature of 49°C, the number of microbes was observed to increase from (48 x 10^6 Count/100 ml to 140 x 10^6 Count/100 ml) in R5, R8 the number of microbes ranged from 44 x 10^6 Count/100ml to 92 x 10^6 Count/100 ml, R9 from 49 x 10^6 Count/100 ml to 136 x 10^6 Count/100 ml, R12 from 50 x 10^6 Count/100 ml to 110 x 10^6 Count/100 ml and R13 from 45 x 10^6 Count/100 ml to 70 x 10^6 Count/100 ml.

At temperature of 45°C the mass of microbes was observed to increase in R1 from 39 x 10^6 Count/100 ml to 93 x 10^6 Count/100 ml, R2 from 30 x 10^6 Count/100 ml to 85 x 10^6 Count/100 ml, R7 from 36 x 10^6 Count/100 ml to 64 x 10^6 Count/100 ml, R14 from 22 x 10^6 Count/100 ml to 61 x 10^6 Count/100 ml, R15 from 34 x 10^6 Count/100 ml to 84 x 10^6 Count/100 ml by considering the samples contained rice husk with the particle size of <3 mm.

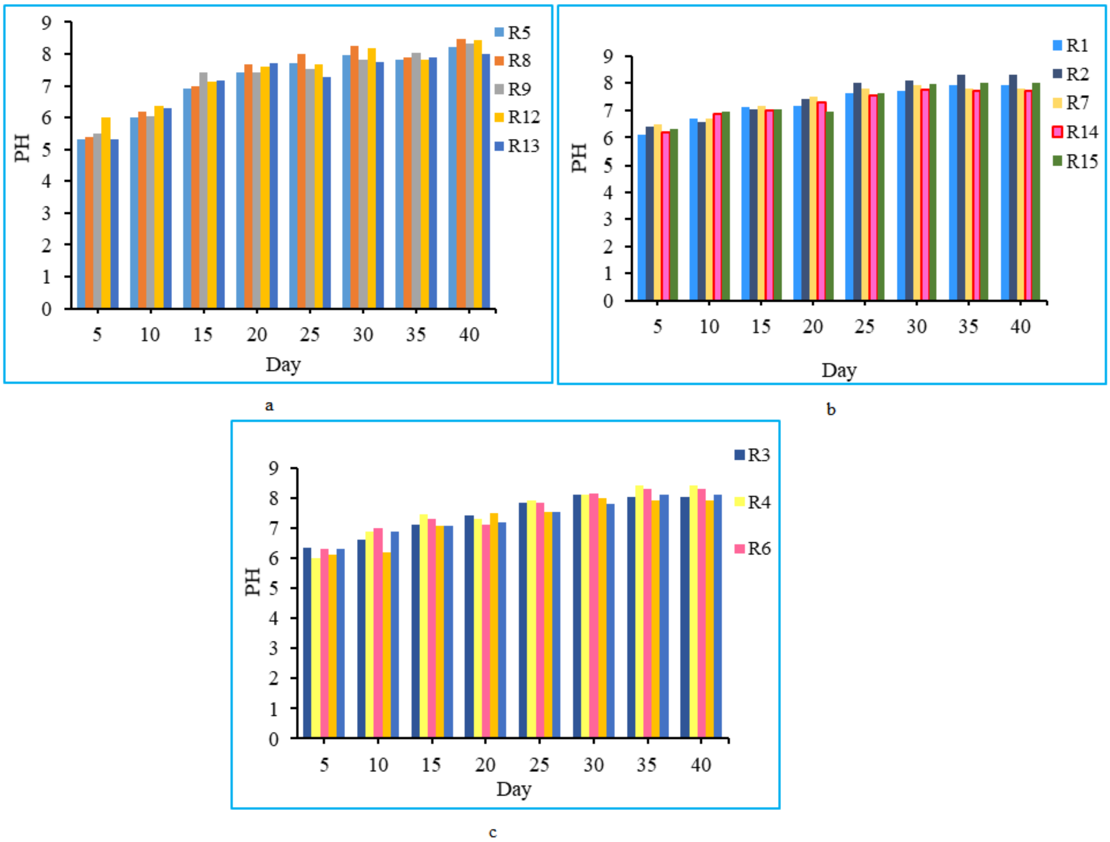

Figure 4. The ranges of pH measured on 5th, 10th, 15th, 20th, 25th ,30th, 35th and 40th days of composting process by considering rice husks with the particle size of <2 mm, <3 mm and <4 mm as labelled in a, b, c respectively.

At temperature of 44°C the number of microbes were observed to rise in R3 from 37 x 10^6 Count/100 ml to 80 x 10^6 Count/100 ml, R4 from 35 x 10^6 Count/100 ml to 79 x 10^6 Count/100 ml, R6 from 40 x 10^6 Count/100 ml to 70 x10^6 Count/100 ml, R10 from 38 x 10^6 Count/100 ml to 87 x 10^6 Count/100 ml and R11 from 35 x 10^6 Count/100 ml to 75 x 10^6 Count/100 ml as composted ratios with the particle size of <4 mm respectively.

The statistical analysis of the correlation analysis indicated a coefficient value of $r > 0.7$ which implied that there was a strong positive correlation between the mass or population/number of microbes and temperature in the interior pile. This association showed that when the number of microbes increases decomposition rate increases and a high amount of heat is given out which contributes to the rise of the inner temperature of the pile (Andoaver, 2014). This was also justified by Sarkar *et al.*, (2015) who narrated that the heat liberated within the pile during the decomposition process is dependent on the population of microbe's act on composting feedstock's material during the process.

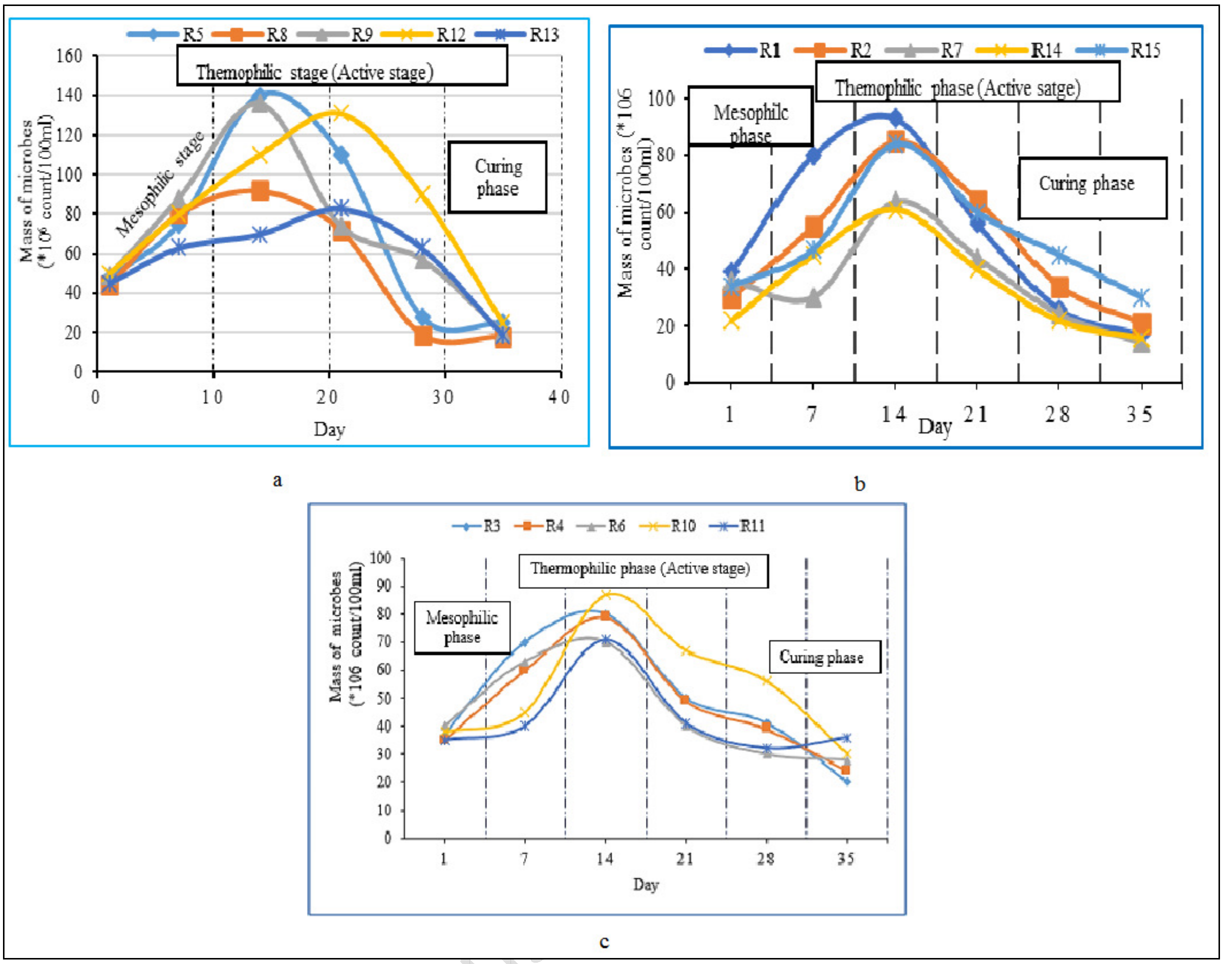

Figure 5. The variation in number of microbe's compost sample ratios on 1st, 7th, 14th, 21st, 28th and 35th days of composting process by rice husks with the particle size of <2 mm, <3 mm and <4 mm as labelled in a, b, c respectively.

At the mesophilic phase (1st phase), mesophilic bacteria and fungi were acclimatized to new environment and started to grow rapidly to all composted ratios as described in Fig. 5 (a, b and c), whereby lowest population observed was 18 x 10^6 Count/100 ml from sample R_8 in 35th day as illustrated in Fig. 5 (a) and the highest was 140 x 10^6 count/100 ml observed in 14th from R_5. This phase the microorganisms use carbon and nitrogen as the sources of energy and protein to generate heat (Pilar *et al.*, 2015). The decomposition of soluble compounds such as sugars, produces organic acids hence would result pH to drop to about 4 or 4.5.

In the thermophilic phase, a mixed population of thermophilic bacteria and most heated tolerant fungi contribute in the breakdown of protein, fat, hemicelluloses and celluloses. The microorganisms that advance at average temperatures as mesophilic microorganisms are replaced by those that grow at greater temperatures which are thermophilic bacteria which increased in 14th day to all composted ratio but the higher microbial concentration was observed in sample R5 and R9 as shown in Fig. 5a which were 140 x 10^6 Count/100 ml and 136 x 10^6 Count/100 ml respectively.

In the curing stage all composted rations were observed to have small population of microbes hence slow degradation of lignin and other highly resistant compounds which may led into the formation of a resistant organic mixture remained called a matured co-compost (Bernal *et al.*, 2017).

Color of the compost during the composting period

The color of the compost was observed to alternate from the initial mixer with a distinctive color of brown like appearance of Rice Husks feedstock and green color of the *azolla* plant to a common dark brown color for all composting ratios containing a rice husks with the particle size of 2 mm, 3 mm and 4 mm which were R3, R4, R5, R7, R8, R9, R11, R12 and R13, R15 except in ratios R1, R2, R6, R10, R11 and R14 materials which were light brown as shown in Fig. 6 (a and b). Such findings coincide with the findings reported by Leslie *et al.*, (2022) and Zein *et al.*, (2015) who indicated that matured compost's colour is dark brown, with a non-offensive, earthy aroma.

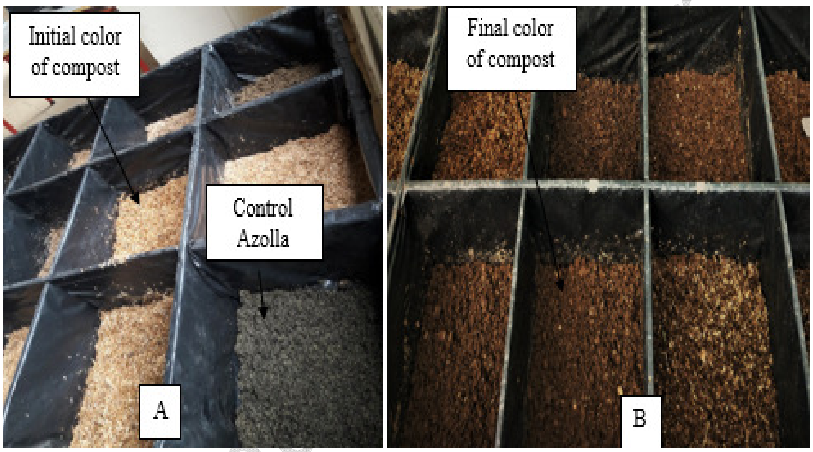

Figure 6. Color of initial feedstock's material and color of final co-compost respectively.

Characteristics of matured compost

The result showed that the highest total nitrogen was 1.575% in ratio R15 while the lowest was 0.835% in R14 as shown in Fig. 7. The highest percentage of nitrogen in R15 was probably influenced by the quality of the feedstock's material and the lower total nitrogen in ratio R14 which is a control composting with rice husks (*Oryza sativa*) only, which could be a result of low total nitrogen in rice husks. The typical range of TN in compost is 1.0 - 3.0% and if the total nitrogen in compost is around 0.6% or less it indicates that there is a chance for nitrogen immobilization and compost of over 3% total nitrogen is usually found to be in immature compost (Costa *et al.*, 1999). Therefore, the compost produced had nitrogen content within the recommended range except for the control sample of rice husks.

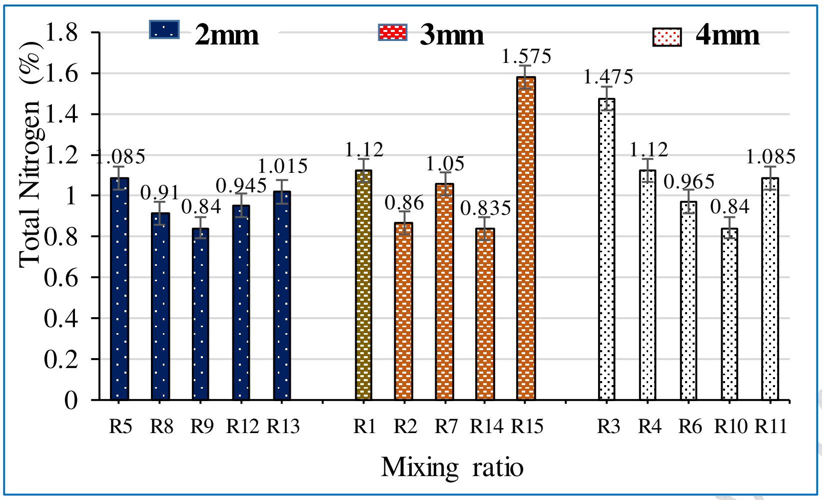

Figure 7. Total Nitrogen content of matured compost in all composting bin

C/N ratio

The highest value of C/N ratio of 38.61 was observed in sample R2 and the lowest value was 21.65 in R3. The higher C/N ratio in R2 was the result of a higher % TC which was 38.6 and low % TN of 0.86. The EPA specifies that the C/N ratio of the compost must be below 25. Therefore all samples of the rice husks with particle size of <2 mm were observed to have a suitable ratio for compost production as described by Golabi *et al., (*2004) that the suitable co-compost should have the C/N ratio of 25:1; 30:1. Also samples with <3 mm from sample R1, R7 and R14 were within the ranges except for composted ratio R2 which was found to be above the recommended limits. Furthermore, R15 and all composted samples with the rice husk of particle size of < 4 mm were not within the range of 25 to 30 as recommended by EPA. The reason for the higher C/N ratio above the limit may be caused by the slow rate of microbial decomposition resulting from the balance of material in terms of quality. A study done by Aondoaver (2014) found out the CN of rice husks at its stage of decomposition was 13:1. C/N ratio provides indication or the ripening of mature compost, therefore R1, R2 and R5 are suitable ratio for compost production using *azolla* plants and rice husks as shown in Fig. 8.

Practical applications of compost produced from *azolla* and rice husks

Plant growth rate

The heights of stem and leaves, widths of leaves, and number of leaves of *Amaranthus spinosus*in plots 1, 2, 3 and 4 were observed to transform, increase and extended over time as described in Fig. 9 concerning their measurements as recorded in Table 4, the width of leaves and stem, plant heights and number of leaves were observed to increase and extended from 1st to 18th day as described in Fig. 10. During monitoring of *Amaranthus spinosus* growth, it was evident that after two weeks, vegetables grown with compost from *azolla* and rice husks exhibited different heights of stem and leaves, width of leaves and number of leaves. Cultivated vegetables with compost shows better growth compared to those under control plot (Barus *et al*., 2023; Saha *et al*., 2003). The study conducted by *Saha et al*., (2003), indicated that the maximum palatability and yield by Amaranthus is obtained at 25 days after sowing the seed. Therefore, observation can be done to observe effective seed germination and yield indication after two weeks from the planting day.

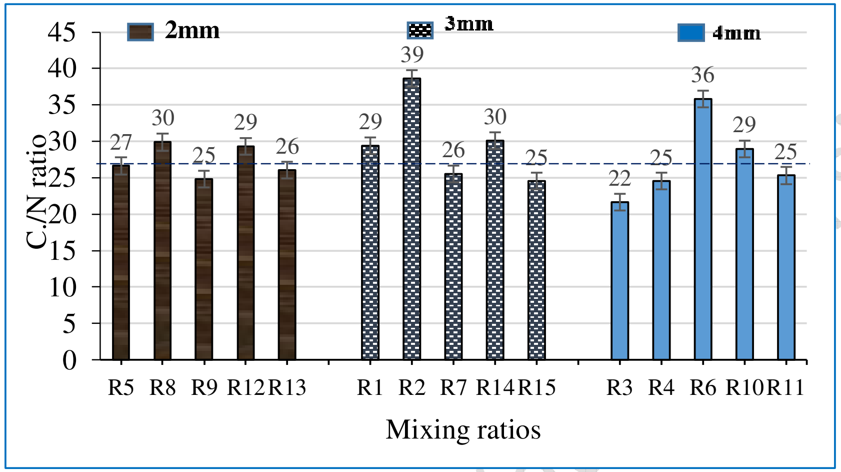

Figure 8. C/N ratio of matured compost in all composting ratio bin

Table 4. Growth rate for *Amaranthus spinosus* by measured length, widths and heights in each plot

	Plot1				Plot 2				Plot 3				Plot 4 (control)			
Day	Hs cm	Ll cm	Wl cm	No. i	Hs cm	Ll cm	Wl cm	No. i	Hs cm	Ll cm	Wl cm	No. i	Hs cm	Ll cm	Wl cm	No. i
1	0	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0	0	0	0
4	2	0.8	0.4	2	1.8	0.6	0.4	2	1.6	0.4	0.3	2	1.3	0.5	0.4	2
8	5	1.3	1	3	4.6	1.9	1.2	3	4	0.9	0.8	2	3.9	0.8	0.9	2
12	9	2.8	1.5	7	6	2.7	1.5	6	5	2	1.3	4	4.2	1.2	1	3
14	13	3	2.1	8	9	3	1.8	6	7	2.2	1.7	5	5	1.2	1.4	4
18	15	4	2.4	10	12	4	2.1	8	9	2.9	2.4	6	6	1.9	1.8	5

Whereby Hs- height of stem, Ll- length of leave, WI- width of leaves and No. i- number of leaves

The capability of plots 1, 2 and 3 to allow the growth of *Amaranthus spinosus* at the rate of 0.9572 cm/day was probably contributed by the quality of compost ratios applied in each plot. This was justified by the regression analysis indicated in Fig. 9 which revealed the r-square of 0.96 which implies that there was significant plant growth as the day's increased.

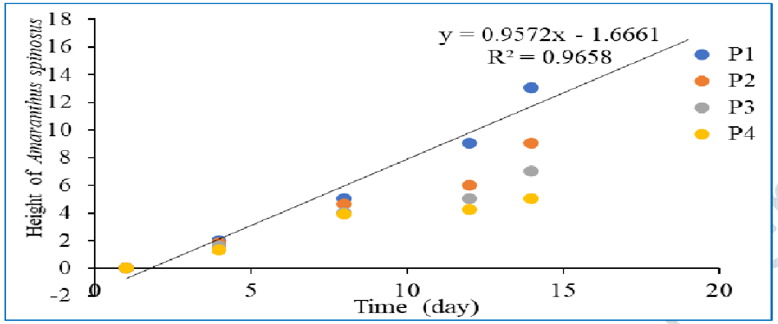

Figure 9. The relationship between height of *Amaranthus spinosus* and monitoring time (days)

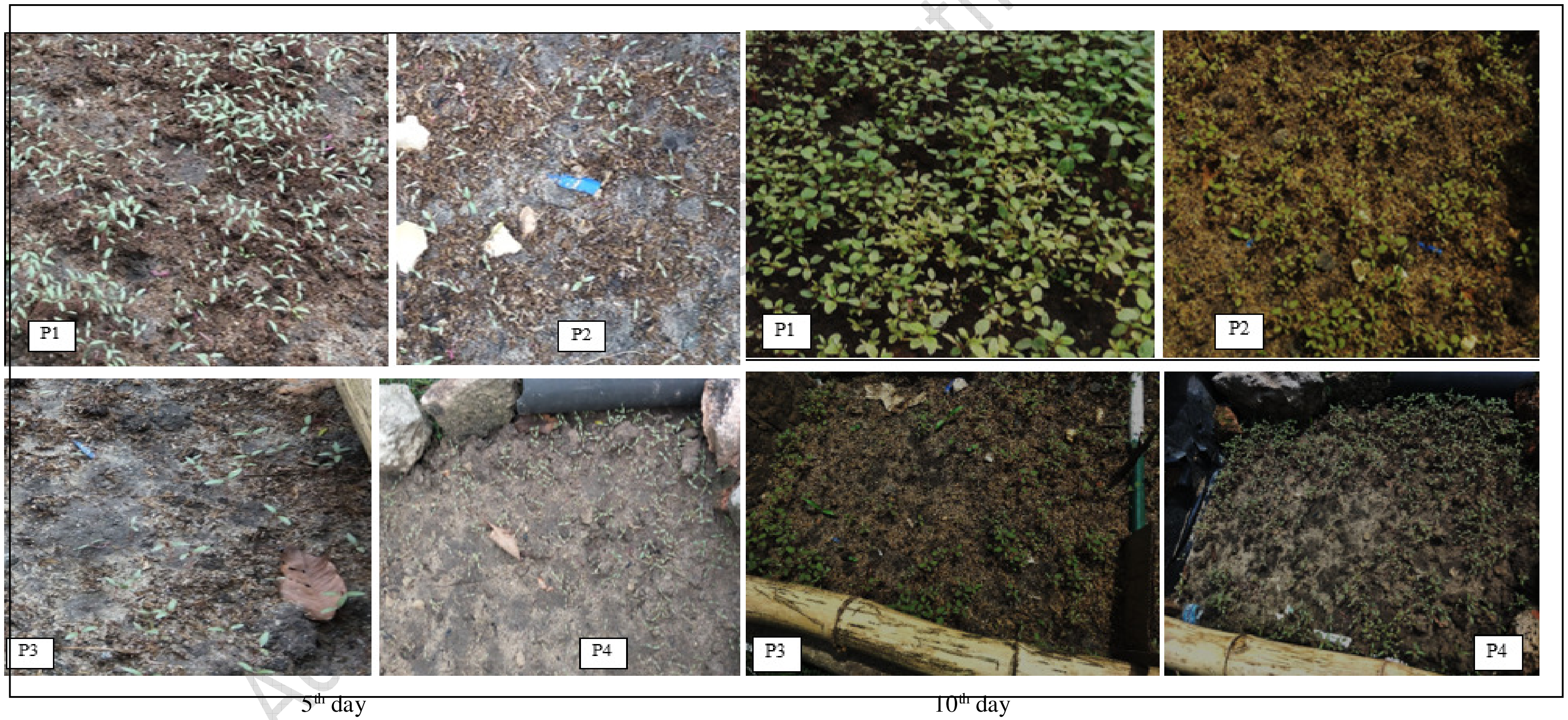

Figure 10. *Amaranthus spinous* on 5th and 14th day in plot 1, 2, 3 and 4.

Conclusion

This study successfully assessed the potential of composting rice husks (*Oryza sativa*) with *azolla* (water fern plant) for agricultural productivity. During the bin composting the rice husks with the particle size 2 mm obtained the highest temperature (49°C) compared to other particle sizes including 3 mm (45°C) and 4 mm (44°C) while 45°C in the thermophilic phase. Compost produced as a result of composting *azolla* (water fern plant) and rice husks (*Oryza sativa*) can be used for fertilizing the soil due to the nutritional properties observed by improving the soil structure and texture. The composting made using samples with particle size of < 2 mm were observed to support the growth of *Amaranthus spinous* quickly with the growth rate of 0.9572 cm/day than other compost produced with particles size of 3 mm and 4 mm. It is the right time to use agro-waste products in improving plant growth as such technology is simple and can be used at a small scale and large scale supporting agricultural productivity. This research recommends further research to determine the heavy metal concentration in the feedstock's material before composts to avoid adverse effects on plant tissues when they may accumulate within manufactured compost before applied into the field for agricultural productivity. Also, follow ups study should establish full characteristics of rice husks and *azolla* including cellulose, hemicellulose and lignin and compare with typical reported values from other literatures.

Author contributions: The authors confirm the study conception and design: Leonard, L.S; conceptualization, data analysis, interpretation of results and manuscript preparations; Chacha, N; conceptualization, data analysis, interpretation and manuscript preparations; Kingshashu, A.Y; experimental set up and data collection and manuscript preparations. The results were evaluated by all authors and the final version of the manuscript was approved.

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